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Near-Earth Asteroids Orbit Propagation with Gaia Observations

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Introduction

Gaia is an astrometric mission that will be launched in 2013 and set on L2 point of Lagrange. It will observe a large number of Solar System Objects (SSO) down to magnitude 20. The Solar System Science goal is to map thousands of Main Belt Asteroids (MBAs), Near Earth Objects (NEOs) (including comets) and also planetary satellites with the principal purpose of orbital determination (better than 5 mas astrometric precision), determination of asteroid mass, spin properties and taxonomy. Besides, Gaia will be able to discover a few objects, in particular NEOs in the region down to the solar elongation 45° which are harder to detect with current ground-based surveys. But Gaia is not a follow-up mission and newly discovered objects can be lost if no ground-based recovery is processed. The purpose of this study is to quantify the impact of Gaia data for the known NEAs population and to show how to handle the problem of these discoveries when faint number of observations and thus very short arc is provided.

1. The Gaia mission

During the 5-years mission, Gaia will continuously scan the sky with a specific strategy: objects will be observed from two lines of sight separated with a constant basic angle. The angle between the Sun direction and the spin axis is set to 45°. The initial spin rate is 1″/min and the spin will precess around the Sun-Earth direction with a mean period of 63 days. Because of this specific scanning law and its positioning, Gaia won't be able to observe down to the solar elongation ~45°. But we do expect some observations and/or discovery of Atira asteroids (moving below the Earth orbit). Two other constants are still free parameters: the initial spin phase which has an influence on the observation's dates and the initial precession angle which has an influence on the number of observations for a given target. Because of this specific scanning law, some asteroids can be well-observed – i.e. the Gaia observations cover at least one revolution period of the asteroids – and some others can be poorly-observed – i.e. the Gaia observations are faint and cover less than half the revolution period.

2. Astrometry for known NEAs

Among the NEAs that will be observed by Gaia, we do expect some observations of Potentially Hazardous Asteroids (PHAs). Those asteroids can show particular threat of collision with the Earth in the future. To illustrate the impact of Gaia observations on PHAs orbit, we will consider here the case of the asteroid (99942) Apophis (previously designed 2004 MN_4). This asteroid will have a deep close encounter with the Earth in April 2029 within ~38000 km and because of the chaoticity of the 2029-post orbit, collisions with the Earth are possible after this date [1].

2.1. *Observations of asteroid (99942) Apophis*

Because of the nominal scanning law of Gaia, and in particular the initial precession angle, the number of observations per object can be inhomogeneous. We can have more than 20 observations as well as less than 10 observations. For our simulations, we chose a set with the longest arc length (with 12 Gaia observations) and with a 5 mas accuracy. This set covers half the orbit of Apophis (Fig. 1).

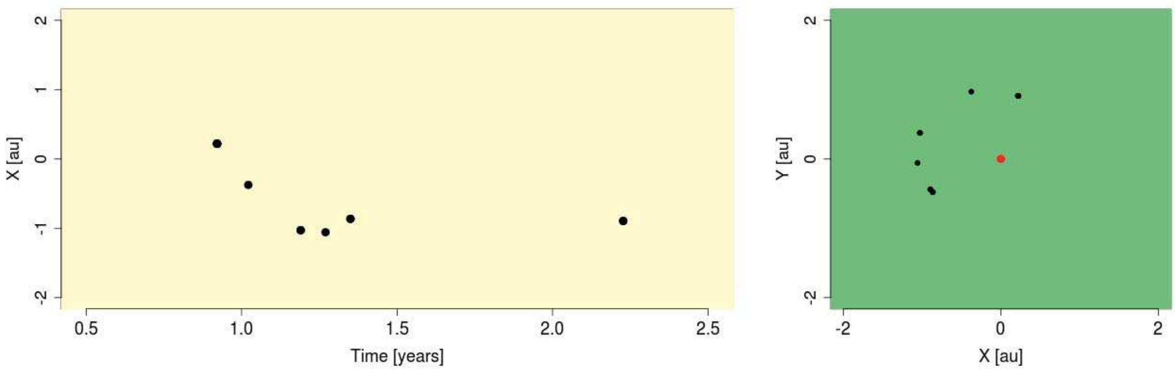

Fig. 1: Left: Gaia observations of Apophis versus time.
The x-axis is expressed in terms of the number of years elapsed since the beginning of the mission.
Right: spatial distribution of the observations in the ecliptic frame and centered on the Sun (●).

2.2. *Orbital improvement*

In the short term, one set of Gaia observations could substantially enhance the current accuracy of the keplerian orbital elements of Apophis (and in general for all the possible observed NEAs). Together with all the available ground-based observations (optical and radar), the Gaia observations will enable to improve the 1σ uncertainty of the semi-major by a factor 1000. Besides, the long term uncertainty can be assessed using a linear propagation of the initial covariance matrix (provided by the least square solution). Comparing various sets of observations (Fig. 2) – each set providing a nominal solution – one can see that one Gaia data (set S_5) is enough to reduce the uncertainty to the same level as for the sets S_3 (with an additional radar data) and S_4 (with an additional optical data). But, the impact of one set of Gaia data is incomparable as the uncertainty is reduced to the kilometer level.

3. Astrometry for newly discovered asteroids

When NEAs are discovered, a strategy of recovery can be undertaken. At the epoch of the discovery, Gaia will provide at most two observations separated by approximately Δt~ 1.5 h. Thus, if it is identified as an alert, those coordinates will be sent to the Earth within 24 h. But Gaia is not a follow-up mission and the newly discovered object can be rapidly lost if no ground-based recovery is performed. A follow-up network for Solar system objects (Gaia-FUN-SSO) has been set-up in order to monitor those asteroids after their discovery [2, 3]. In order to optimize the alert mode, we have first to quantify the number of alert expected.

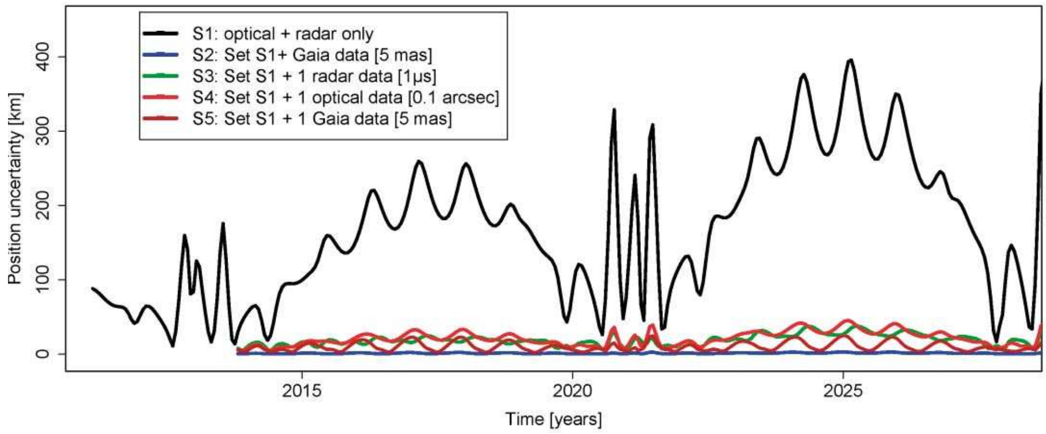

Fig. 2: Position uncertainty propagation considering various sets of observations. While S_3, S_4, S_5 reduce the uncertainty to the same level, S_2 (using a set of Gaia data) decreases the uncertainty to the kilometer level.

3.1. *Near-Earth asteroids alerts*

We presently know more than 9000 NEAs and only ~1/6 of this population could be observed by Gaia. For the discovery quantification, we consider a synthetic population of 30000 NEAs from the model of [4], limited to H ≤ 22.0. We represented in Fig. 3 both the known and synthetic NEAs population that will be observed by Gaia. These populations are represented in the (a,H) space.

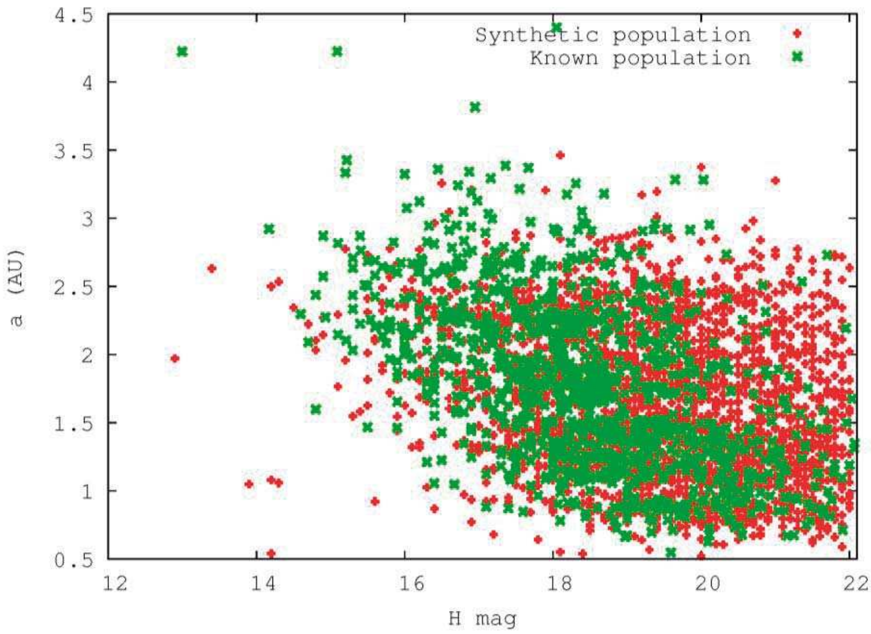

Fig. 3: Representation of the known (×) and synthetic (+) populations possibly observed by the satellite Gaia during the mission.

In order to identify and quantify the number of alerts per year after the beginning of the mission, we removed all the synthetic NEAs for which the semi-major axis *a* and absolute magnitude *H* lie between the minimum and maximum values of (a,H) defining the known NEAs population observed (see Fig. 3). The results are presented in Fig. 4 and show a mean of 4 or 5 alerts per week during the first 4-years after the start of the mission.

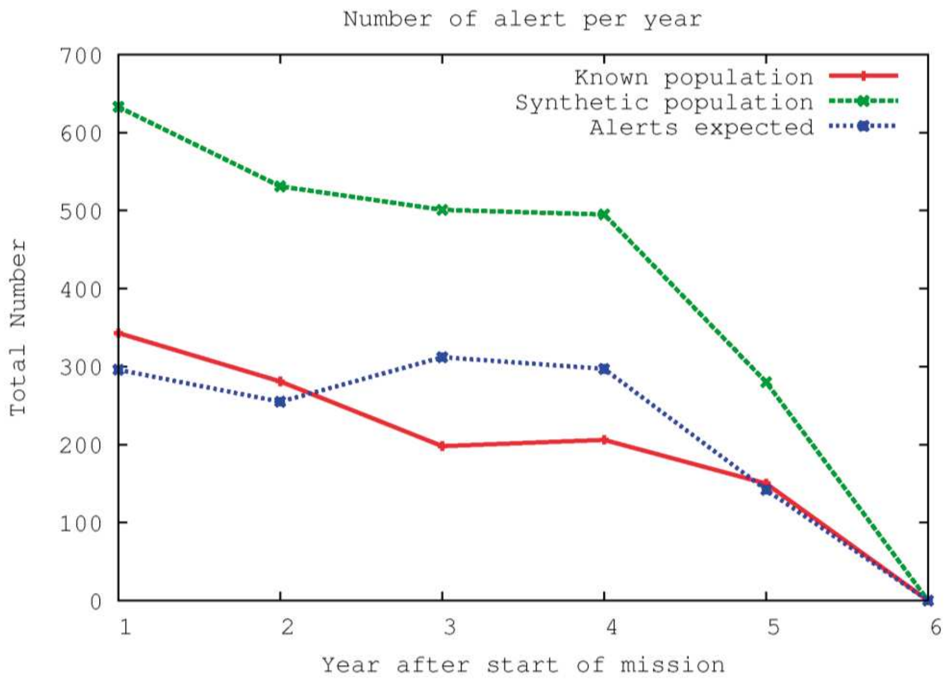

Fig. 4: Number of alerts (■) compared with the number of observed synthetic NEAs (■) and known NEAs (■), per year after the beginning of the mission.

3.2. *Strategy of recovery*

When an alert occurs, a preliminary short arc orbit can be computed with the two (*α, δ*) Gaia observations using the Statistical Ranging method[1][5]. Thus, a distribution (*α, δ*) can be assessed until a certain number of days after the discovery. Because the distribution can be quite large, we used statistical tools to extract the maximum likelihood (ML) of the distribution. Compared to the theoretical position of the object (given by the orbital elements from astorb database), we can estimate the minimum field of view (FOV) required to recover this object. As shown in Fig. 5, some asteroids will need typical FOV < 25×25 arcmin^2 (case of asteroid Cuno) until 10 days after their discovery, while some others (case of asteroids Apophis and Phaethon) require a FOV of hundreds of square degrees after their recovery. This behavior can be explained by their relative distance to the Earth – Geographos and Cuno are relatively far from the Earth (> 1 AU) at the epoch of their discovery by Gaia, and less perturbed by the Earth than the others (distance to the Earth <0.5 AU).

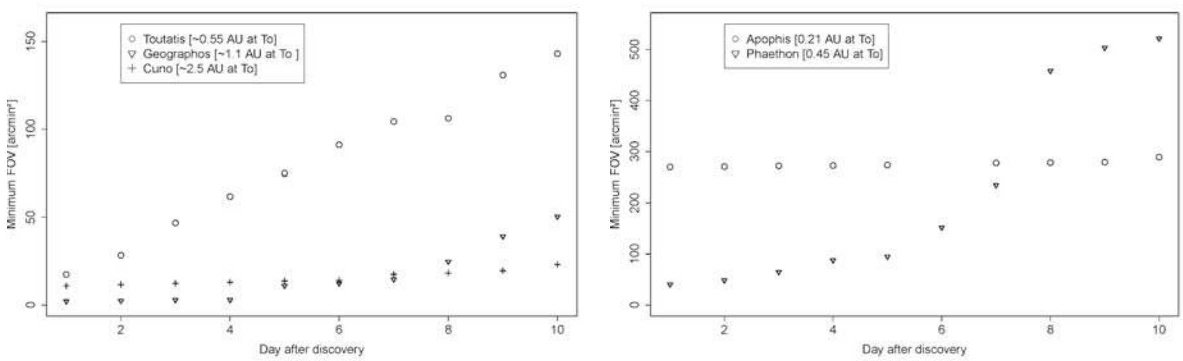

Fig. 5: Variation of the minimum FOV required for the recovery process versus time.
Left panel: for the asteroids Toutatis, Geographos and Cuno.
Right panel: for the asteroids Apophis and Phaethon.

[1] This method uses Monte Carlo technique on the (α, δ) observations and on the topocentric distances

Finally, when the object is recovered by the Gaia-FUN-SSO, complementary ground-based measurements will enable to improve the orbital elements and the quality of the orbit. This process will enable to optimize the short-term pipeline and the organization of the network in as much as, the orbital improvement will enable to use telescopes with smaller FOV and keep the larger ones for asteroids requiring large FOV during the recovery process.

Conclusion

Even if Gaia will not be a big NEAs discoverer, there is a need of the science community to support the Gaia mission in order to be ready for this opportunity of discovering new NEAs. Among them, there could be some threatening potentially hazardous asteroids and we cannot afford to lose them is no Gaia-FUN-SSO is well organized

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